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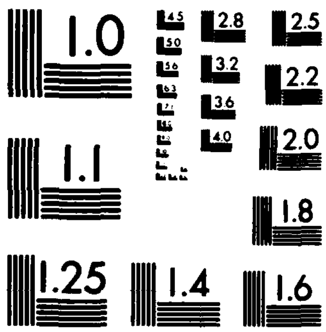


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# a review of the literature on training simulators: transfer of training and simulator fidelity

yuan-liang david su

report no. 84-1

april 1984



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes and evaluates a number of transfer of training methodologies. Definitions and components of simulator fidelity are discussed. The issue of fidelity measurement is investigated and the relationship between fidelity and training effectiveness is explored.

# A REVIEW OF THE LITERATURE ON TRAINING SIMULATORS: TRANSFER OF TRAINING AND SIMULATOR FIDELITY

BY

YUAN-LIANG DAVID SU



Report No. 84-1

April 1984

TABLE OF CONTENTS

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# A. INTRODUCTION

Traditional approaches to training on actual equipment are becoming more and more prohibitive because of relatively high cost and their limited ability to be used for training on unusual or potentially catastrophic situations. Simulators are used to cope both with increasing costs and limitations on training effectiveness. Spangenberg (1976) discussed seven unique advantages of using simulators for training. Simulators can (1) provide immediate feedback, (2) increase the number of system malfunctions and emergencies to provide the trainee with experience which would be unavailable on actual equipment, (3) compress time so a complex sequence of tasks may be accomplished in the time it would take to run through only one or two tasks on the actual equipment, (4) vary the sequence of tasks to maximize training efficiency, (5) provide guidance and stimulus support to the trainee in the form of prompts and feedback, (6) vary the difficulty level to match the skill level of each individual trainee, and (7) provide the trainee with an overview from which the trainee may form an overall understanding of the whole situation. These advantages, in addition to the potential cost-effectiveness are the reasons why simulators have been widely used.

Simulators take various forms. These include mock-ups, photographic mimics, and computer graphics. Usually they are

less expensive than real systems. However, large mock-ups like those used to train pilots are expensive. The cost of a simulator usually increases with the fidelity of the simulator even though increased fidelity does not guarantee better training. Several terms used frequently in this area are defined below and are followed by a general overview of this report.

## DEFINITIONS

A "simulator" is a device or a facility which represents a machine, system, or environment and its functions (Gerathewohl 1969). Simulators have been widely used to train operators for maintenance, normal operations, problem-solving, and decision making. Simulators have been constructed for a variety of applications. Clymer (1980) identified at least eight different types : aircraft, aerospace, marine, ground vehicle, traffic, process plant, power plant, and manufacturing plant. The term "training device", and "trainer" are very often used to mean the same thing as simulator, although some slight differences can be distinguished between them (Gagne 1954).

"Fidelity" and "realism" are terms used frequently in the simulation and training community. However, their definitions are not clearly stated. A more comprehensive discussion of fidelity will be presented later in this report. For now it is sufficient to note that fidelity or realism refers to the degree

to which a device or a facility accurately simulates a machine or a system. It is generally believed that high fidelity training devices cost more than low fidelity devices. A simulator that incorporates only those features that are necessary to train for a given task has the highest potential for cost-effectiveness.

Suitable means must be devised to evaluate the effectiveness of training programs. The extent to which a given simulator facilitates the acquisition of appropriate skills by the trainees is characterized by "transfer of training" from the training devices to actual equipment, "training effect" or "training effectiveness". These terms are also used to describe the effectiveness of a training program which may or may not include a simulator. In this report these terms will be used primarily for the former case. Conventionally, simulators have been employed in training with the assumption that higher fidelity produces a better transfer effect. However, research that contradicts this assumption has also been reported during the past few years (see Section D).

## OVERVIEW

Simulator training is only one option for a training program. Other available options include classroom lectures, books and manuals, slides, movies, demonstrations, practice on real equipment, and on-the-job training. Whatever options are

used, they are all intended to facilitate the human learning process. Therefore, Hennessy (1981) comments that most problems associated with simulator training are not any differenc from those in other types of training. What makes the simulator training unique are the complexity of the equipment involved and the cost of simulators.

Several factors can affect the effectiveness of simulator training. These include instructors' roles, user acceptance, management support, student characteristics, simulator fidelity, training strategy, training time, and pretraining knowledge. Among these factors, only simulator fidelity will be covered in this report. This does not imply that the other factors are unimportant. Consideration of the effects of all revelant factors would be beyond the scope of this report.

Training simulators may consist of several subsystems which interact with each other. Since each subsystem may contain hundreds of indicators and gauges, it can be expensive to construct and run such a simulator. Therefore, the question of how to efficiently utilize simulators becomes important. This problem has been investigated in Section B.

A distinction between two types of training is made in Section C. The state-of-the-art on simulator training is also described. Then "training effectiveness" and "fidelity level"

are discussed. These two problems are discussed in almost every study of simulator training. The evaluation of training effectiveness of simulators in terms of the experimental paradigm commonly used, measurement, criticism and modification is also provided in Section C.

Section D describes the issue of simulator fidelity, including its definition, relationships with training, measurement and components. Finally, potential research approaches to training are described in Section E.

## B. OVERALL REVIEW OF SIMULATOR TRAINING

Two types of simulator training can be identified. One is training for system operation and the other is training for maintenance, i.e., fault diagnosis or troubleshooting, repair, and tests to assure normal operation.

In training for operation, the trainees do not know how to operate the system before training begins. However, they may possess some basic knowledge about the system operation. For example, a training simulator for a Boeing 747 aircraft may be designed under the assumption that the trainees already know how to fly other types of airplane. However, nothing in the B-747 simulator should be left out solely on the basis of trainees having flown other aircraft. Although operations under normal conditions are usually implied, this type of training could, and perhaps should, involve operations under abnormal conditions or degraded mode.

In training for maintenance, the trainees must have learned to operate the system under normal conditions. Hence, this type of training can be thought of as forming the second stage of a training program. In the following discussion, greater emphasis will be placed on fault diagnosis or equivalently described as troubleshooting.

This distinction is important since the characteristic differences between them result in different approaches.

## TRAINING FOR OPERATION

Training for operation emphasizes visual-motor coordination types of task, such as steering a vehicle, or flying an airplane. The physical layout, environmental factors, handling quality, visual and motion cues, scenic view, and vibration are all reported to be influential factors on training effectiveness (Semple et al. 1981, Martin and Waag 1978). Relatively high simulator fidelity is generally provided for this type of training (Baum et al 1982), although the required degree of fidelity is not known. Expensive mock-ups are widely used for training of this type. However, less expensive equipment such as three-dimensional computer graphics simulators and simulators with computer-generated imagery (Forbus and Stevens 1981) have been investigated as substitutes for mock-ups. The target task is relatively well understood and therefore the training objectives are usually well defined. The transfer effects are sometimes difficult to determine due to the cost and risk of operating the real system.

## TRAINING FOR TROUBLESHOOTING

In training for troubleshooting greater emphasis is placed

on the acquisition of procedural or cognitive skills, such as failure detection, fault diagnosis, problem solving, decision making and information seeking. Some empirical evidence has been accumulated to justify the use of low fidelity simulators for this purpose (Crawford and Crawford 1978). It is argued by most researchers that the cognitive nature of the problems instead of visual-motor coordination is more important. The target task is relatively difficult to define.

In a fault diagnosis situation, it is possible that some failures and their causes may not be known in advance. It is infeasible to train the operator for all cases. The objective of training of this type is therefore the acquisition of general diagnostic ability. In other words, the rationale of using a fault diagnosis simulator for training is that general diagnostic ability can be developed through the exposure to specific diagnostic experiences. It is thus assumed that the learning of many similar fault diagnosis tasks in a simulator results in the gradual development of the problem solving ability for the simulated system. The transfer effect is difficult to determine due to the lack of suitable metrics for cognitive skills as well as practical limits on one's ability to present realistic troubleshooting problems for the purpose of measuring transfer of training.

## STATE-OF-THE-ART

Simulator training has been studied extensively since World War II. Gagne (1954) summarized the research up to 1954 and pointed out the problems and future research directions. Twenty-seven years later, Hennessy (1981) indicated that research on simulator training since Gagne has done very little to improve our understanding. Most of the outstanding research issues were the same as those pointed out by Gagne. Many studies were conducted to evaluate the effectiveness of particular pieces of equipment. Cost effectiveness analysis was another highly investigated area. Training strategy and instructional methods were investigated broadly. Several performance measures have been developed and used. Hennessy (1981) presented a summary of the current research issues on simulator training. After a relatively extensive literature search, a modified and extended list to his original presentation was compiled and is shown below.

1. Training Strategy :
   - Adaptive or fixed amount of training
     (Freedy and Lucaccini 1981)
   - Self-paced or fixed schedule
   - Optimal use of simulator (Weitz and Adler 1973)
   - Total information or withheld information
     (Duncan and Shepherd 1975)

2. Instructional Methods :

- Role of the instructor

  involved and directive or provide error feedback only

- Instructor model (McCauley et al. 1982)

- Knowledge of results

  error or accuracy

  augmented or intrinsic

- Learning situation

  team training or individual training (Eggemeir and Cream 1978)

  learning style

3. Training for Normal Operation :

- Evaluation of device effectiveness (Finley et al. 1978)

- Whole or part training

  can complex skills be trained separately?

  are components separable?

  are they learned at different rates?

- Retention of training (Goldberg et al. 1981)

- Effectiveness of a particular factor

  visual cues, motion cues, vibration etc. (Semple et al. 1981)

4. Maintenance and Procedural Training :

- Evaluation of device effectiveness
  (Fink and Shriver 1978)
- Retention of training (Johnson 1981)
- Model of problem-solving (Rouse 1981)
- Development of system (Johnson and Fath 1983)
- Affective factors (Morris and Rouse 1983)
- Aiding (Lintern 1980)

5. Training Device Design :
   - Design guidelines (Van Cott and Kinkade 1972)
   - Device requirement and characteristics (Miller 1974)
   - New devices and approaches (Levin and Fletcher 1981)
   - Use of microcomputer (Crawford and Crawford 1978)

6. Performance Measure :
   - What to measure

     measures of problem solving performance
     (Henneman and Rouse 1984)

     criterion-referenced measure (Swezey 1978)
   - Reliability and validity (Goldstein 1978)
   - How to measure

     formulas for transfer of training
     (Hammerton 1977)

     rating (Cooper and Drinkwater 1971)

     transfer function (Matheny 1978)
   - Predictive index

measurement of fidelity (Narva 1977)

- Task analysis

    basis for fidelity measurement (Hays 1981)

    basis for device requirement

    (Wheaton et al. 1976)

7. Cost-effectiveness of Training Devices :

- Cost effectiveness analysis

    (Orlansky and String 1981)

8. Methodology Consideration :

- Transfer of training

    in-simulator transfer of training

    (Westra 1981)

    criticism (Adams 1979)

Training effectiveness is the major concern of most of the research mentioned above. The selection of training strategy and instructional method, design of training devices, determination of cost effectiveness, and adoption of suitable predictive indices are based on the measurement of training effectiveness. To determine cost effectiveness, measures for training effectiveness and cost are needed. These in turn are based on different types of data and measurement methodologies. Even though cost effectiveness is the most important factor when a decision on the procurement of simulators must be made, such

decisions will not be considered here since they are beyond the scope of this report.

The next section will discuss the issues concerned with evaluation of the training effect, including the paradigm, performance measures, modification to the paradigm and criticisms of the paradigm.

## C. EVALUATION OF TRAINING EFFECTIVENESS

Several methods have been proposed to assess the effects of simulator training upon operator performance in a real system. These methods have included comparison with a control group (in a transfer-of-training experiment), comparison with a model of optimal performance, and subjective ratings. However, only transfer of training and subjective ratings have been widely used and studied. Transfer of training experiments may be costly to conduct but the result is definitive. Subjective ratings are easier to collect but the result, being subjective, may not be definitive with regard to actual effectiveness. Rating studies are widely used to predict the effectiveness of a simulator when an emperical data base is not available, while transfer of training studies are used to estimate the observed effectiveness of a simulator.

### TRANSFER OF TRAINING

Transfer of training is an old issue in psychology. Gagne et al. (1948) conducted a comprehensive review of the measurement of transfer of training used by experimental psychologists. Murdock (1957) outlined the paradigms used by transfer experiments. He pointed out that some means of comparing the amount of transfer resulting from distinct measures were important. Osgood (1949) investigated the transfer effect

in a stimulus-response context. In his studies, subjects were first taught to associate a specific stimulus with a specific response. Subjects were then tested on other stimulus-response pairs which might deviate from the original one. Osgood reported that the similarity between the tested S-R pairs and the original S-R pair could affect the transfer effect. He proposed a "transfer surface", based on which two conclusions could be drawn:

(1) When stimuli are varied and responses are identical, positive transfer is obtained.

(2) When stimuli are identical and responses are varied, negative transfer is obtained.

In other words, the degree of similarity between the stimuli and between the responses determines the positive or negative transfer. The motivation of using a simulator as a training device is the hope that positive transfer of training can be elicited. Therefore studies of transfer of training from the simulator to the real system have long been used to evaluate the effectiveness of a training device. The paradigm commonly used, the performance measures and their drawbacks, and modifications are presented in the following paragraphs.

## The Paradigm

Valverde (1973) presented a comprehensive review of transfer experiments conducted with aircraft during 1949-1971. Finley et

al. (1972), Meister et al. (1971), and Ryan et al. (1972) have conducted a number of studies on evaluating the effectiveness of naval training devices. Most of the transfer experiments reviewed were based on the same paradigm which is depicted below.

| | simulator training | real system training |
|---|---|---|
| experimental group | yes | yes |
| control group | no | yes |

The experimental group went through two sections of training. The first section was the simulator training while the second section was the real system experience. The control group experienced only the second section. Both sections were considered as complete after stable performance above some criterion was demonstrated. The performance of both groups in the second section was then compared to see if training in the first section influenced the training in the second section. Conventionally the second section was conducted using a real system.

## Performance Measure

Transfer of training effects are usually measured in two ways (Hammerton 1967): (1) savings measure, and (2) first-shot measure. The savings measure determines the reduction of the training efforts in the second section. The first-shot measure

evaluates the performance of the trainee on the first trial of the second section.

(1) Savings measures

The performance measure adopted widely is the percent transfer based on improvement in performance on the real system. The following formula is used extensively (Micheli, 1972).

percent transfer = (c - e)100/c

where:

c = performance or time of the control group on the real system to achieve some criterion

e = performance or time of the experimental group on the real system to achieve some criterion

Roscoe (1971) argued that the transfer measure is more meaningful if the time spent on the simulator is also considered. Therefore he developed the Transfer Effectiveness Ratio (TER). TER is a measure for assessing the effectiveness of a simulator by expressing the savings in time on the real system as a function of the time in the simulator. It is defined as time saved in the transfer task over the time required in the simulator. Therefore,

TER = (c - e)/te

where

c = time to reach some criterion on the real system by control group

e = corresponding value for experimental group

te = time experimental group spent on simulator

(2). First-shot measures

The performance measurement problem is complicated by the fact that, in some practical situations, the "control group" data are not available or the simulated task is more difficult than the real task. The first shot measures can be employed to solve these problems. Hammerton (1967) discussed four of them. The following notations were used (see Figure 1).

F : initial error score on the simulator for the experimental group

T : initial error score on the real system for the experimental group

C : initial error score on the real system for the control group

L : error score after stable performance on the simulator for experimental group

S : error score after stable performance on the real system for control group

The following measure assesses how much training was retained on first transferring to the real system.

$$\text{percent of training retained} = (F-T)100/(F-L)$$

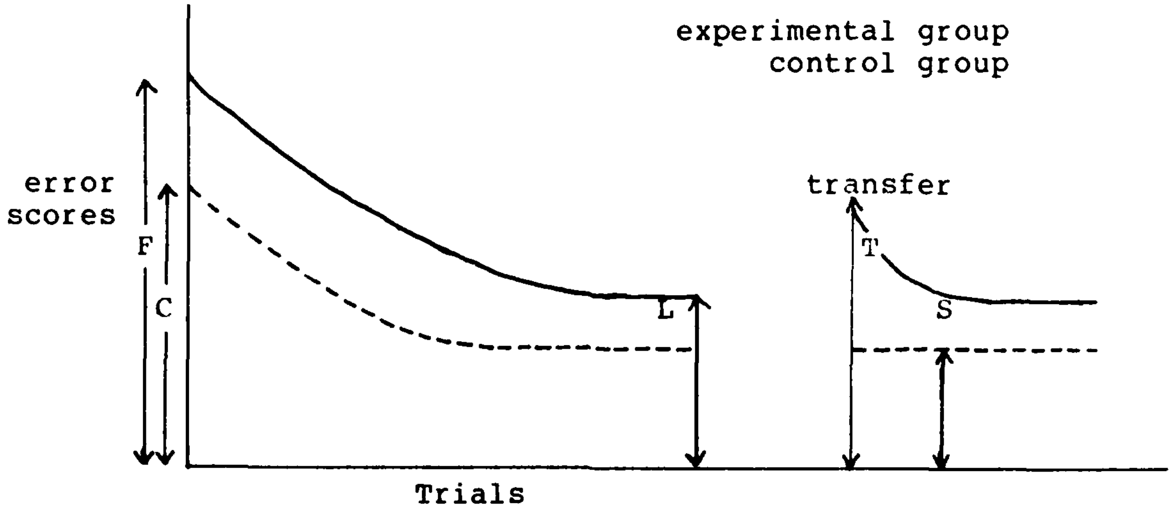


Figure 1 : Curves showing form of typical transfer experiment (modified from Hammerton 1967)

For most purposes this is entirely satisfactory. However, sometimes the simulated task is harder than the real one. Therefore S may differ significantly from L. Also F would be significantly larger than C. In such a case, this formula can make the simulator appear more effective than it really is. Hence, comparisons of first-shot transfer with the stable preformance of the control group is preferred.

percent of training retained = (C-T)100/(C-S)

Note that in this formula C, S and T are measured on the real system. The role of the simulator is only expressed indirectly in T which is the error score of the first trial on the real system after stable performance has been reached on the simulator. Another way to solve this problem is to measure how much learning is retained at transfer compared with that which the experimental group would have required to reach the stable performance level of the control group.

percent of training retained = (F-T)100/(F-S)

The last measure shows how first-shot transfer differs from the stable performance of the control group.

percent of deviation = (1-T/S)100

Appropriate measures should be selected with caution so that no inferences are based on weak measures. Use of these two types of measure (i.e., savings and first-shot) is not without limitation. Hammerton (1977) noted that these two classes of measures really dealt with different things. High savings measures did not imply high first-shot measures automatically and vice versa.

## Criticisms and Modification

Although the transfer of training methodology is widely used it is not without flaws. As a matter of fact, the problems of using a transfer of training measure to assess the effectiveness of a simulator are significant. Several researchers have pointed out the drawbacks and have proposed remedial procedures.

Mudd (1968) pointed out that the transfer approach is not applicable in those situations where the system being simulated is not yet operational or where the system is so complex that it would be disastrous to use an untrained control group. Another disadvantage of the transfer approach is that generalization to new systems is not possible, so each new system needs a transfer study to determine its effectiveness.

Reviewing the effectiveness of flight simulators, Adams (1979) claimed that there are two reasons why it is hard to find

a suitable transfer study.

(1) The cost of a transfer experiment for the simulator of an advanced aircraft is high.

(2) The transfer experiment is simply unsuited for advanced aircraft because it is hard to believe that the control group --- without prior training on the new advanced aircraft --- can be allowed to fly.

He argued that a simulator need not necessarily be tested if it is based on reliable scientific laws and the success of other systems based on the same laws has been high.

Blaiwes, Puig and Regan (1973) maintained a similar view on transfer of training as a measure for the effectiveness of training devices for military usage. They claimed that the difficulties of adopting transfer measures include: (1) the dangers in employing a no-training control group, (2) the difficulties in specifying appropriate performance measures and criterion levels, (3) the problems in specifying appropriate training goals and the need for task analyses, (4) the problems of recording performance measures in training and operational environments, and (5) the confounding of variables in training and transfer situations due to an inability to exercise experimental control.

To circumvent these difficulties involved in using transfer of training, they suggested the four-level evaluation procedure

which was proposed by Jeantheau (1971). The first level of evaluation is a qualitative assessment. It involves examining the procedures used for training in terms of specified objectives, and examining the device design in terms of the degree to which these procedures can be implemented. The second level of evaluation involves measurement of trainee performance from the beginning of training to the end of training. This type of assessment is not comparative, in the sense that performance measured in the trainer is not compared with alternative methods of training. Level three involves comparative measurement. To insure comparability, evaluations should be conducted in a way such that comparisons are made between: practice vs. nonpractice, different training methods or different devices. Level four is transfer of training as depicted before.

Duncan and Shepherd (1975) criticized the transfer of training study as inadequate to assess the training effectiveness for fault diagnosis behavior. Infrequent and irregular occurence of failures make it difficult to measure the transfer effect of fault diagnosis training. Duncan and Shepherd tended to think of the detection of each individual failure as a separate task requiring training. This is different from viewing fault diagnosis as a single task. Suppose the failure is "Heat Exchange Pump Stops". The trainees had to learn how to identify this failure and take remedial actions. However, Duncan and Shepherd argued that one cannot wait until "Heat Exchange Pump

Stops" happens in a real system in order to test the effectiveness of simulator training. Hence, Duncan and Shepherd claimed that a transfer of training study is not an adequate method to assess the effectiveness of diagnosis training.

Shepherd (1977) argued that instead of measuring the transfer effect of a whole simulator, a measure along each fidelity dimension should be more appropriate. For example, how does color, size, or panel layout affect training effectiveness? How does temporal fidelity affect the strategies adopted by the trainee? Unfortunately, no empirical data were provided. Also, there still is a problem of how to measure each fidelity dimension.

Johnson and Rouse (1982), discussed the transfer of fault diagnosis ability from simulators to a live system. Instead of regarding each failure as a task like Duncan and Shepherd did, they treated fault diagnosis behavior as a whole. Transfer of training was then investigated to compare the effectiveness of different training methods. In their study, the fault finding problems on the live system were safer and less expensive to manipulate than those claimed by Duncan and Shepherd to occur infrequently and irregularly.

Conventionally, the transfer effect is measured on the real system, which in some sense, is just a perfect mockup. However,

there are many difficulties in simulating the psychological factors that have been reported to influence the operator's decision making. Realizing these implicit difficulties and the cost of conducting the transfer experiments with the real system, one variation has been tried without training on the real system: within-simulator metrics of transfer of training.

Shepherd et al. (1977) adopted within-simulator metrics to measure training effectiveness. The trainees were trained and tested using the same simulator. Shepherd et al. collected a set of sixteen failures and separated them into two groups of eight failures each. The subjects were trained on one group of failures and tested on the other group. All experimental manipulations were conducted within the same simulator.

Westra (1981) also adopted the within-simulator transfer of training paradigm in his study of carrier landing. The subjects were trained under various conditions and then tested under a standard condition that represented maximum realism. This approach permitted a relatively large number of variables to be studied. Among the variables investigated, three most significant factors were chosen for a further simulator-to-real-system transfer of training study. Thus the within-simulator transfer study was used as a selection tool for features to be included in a further more costly and difficult transfer study.

## Summary

Transfer of training studies have long been used to assess simulator effectiveness. The paradigm involves providing an experimental group with experience, first on a simulator, and then on the real system. The control group is trained only on the real system. Performance on the real system for both groups is compared to determine the effectiveness of the simulator. Time savings measures and first-shot measures are the most commonly used performance measures. In training for normal operation, the transfer of training studies are not adequate for measuring the effectiveness of training devices unless a control group can be formed appropriately. In training for fault diagnosis, if each failure is viewed as a separate task, the transfer of training studies are not suitable for measuring effectiveness since the failure may occur infrequently and irregularly in the real system. However, if fault diagnosis ability is viewed as a somewhat context-independent ability, then the study of the transfer of training is more meaningful.

Within-simulator transfer of training has been used as a substitute to the conventional paradigm. The performance of both control group and experimental group is measured on the simulator. No real system performance is involved. This method is especially useful for measuring training effectiveness for fault diagnosis tasks.

In general, transfer of training studies are adopted most often to assess the transfer effect, though some modifications may be necessary. There are, however, certain situations to which the transfer of training method cannot be applied. Other methods such as ratings should be adopted to ensure appropriate measure of training effectiveness.

## RATING

Ratings have been used widely in the evaluation of flight simulators. Typically, the raters are experienced users of the actual system. They go through the training program and gain a general impression of the simulator before they rate the effectiveness of the tested simulator according to some scale. Ratings are also used extensively for prediction of the effectiveness of training devices. Caro (1970), Wheaton et al (1976), and Narva (1977) relied on ratings as the basis of a predictive model of the effectiveness of training devices. Raters were asked to assess the training technique, physical and functional similarity and the learning deficit. Scores were derived from ratings. Those scores were then transformed into a global index which was used to predict the training effectiveness.

Ratings are usually accomplished through appropriate use of scales. The validity and the reliability of the scales used are

seldom verified due to cost. Two examples of such scales are presented in the following paragraphs.

## Rating Scales

A six-point rating scale used by Gerlach et al (1975) in their study of landing simulation is reproduced below.

| Rating | Adjective | Description |
|---|---|---|
| 1. | Excellent | Virtually no discrepancies between real systems and simulators |
| 2. | Good | Very minor discrepancies |
| 3. | Fair + | Simulator is representative of the parent system |
| 4. | Fair - | Simulator needs work |
| 5. | Bad | Simulator is not representative |
| 6. | Very bad | Possible simulator malfunction |

Class 1 through class 3 are deemed as satisfactory while class 4 through class 6 are unsatisfactory.

A sequential pilot-rating decision scale was proposed by Cooper and Harper (1971). This was a ten-point scale which guided pilots through the estimation process by identifying 3 major characteristics: controllability, acceptability and satisfaction. The raters began with controllability. If the simulator was not controllable then it was rated 10. Otherwise a check was made to see if it was acceptable. If unacceptable, the

simulator was rated 7, 8 or 9 according to its deficiencies. If it was acceptable but not satisfactory, then the simulator was rated 4, 5 or 6 according to the identified drawbacks. If it was satisfactory, then it was further rated into 1, 2 or 3 according to its features. The scale is summarized below:

| | |
|---|---|
| | 1. Excellent, highly desirable |
| Satisfactory | 2. Good, negligible deficiencies |
| | 3. Fair, some mildly unpleasant deficiencies |
| | 4. Minor but annoying deficiencies |
| Acceptable | 5. Moderately objectionable deficiencies |
| | 6. Very objectionable but tolerable deficiencies |
| | 7. Adequate performance not attainable with maximum pilot compensation |
| Controllable | 8. Considerable pilot compensation is required for control |
| | 9. Intense pilot compensation is required to retain control |
| Uncontrollable | 10. Lost control |

## Criticism

Although the acceptance of simulator ratings for inference about the training value is convenient and economic, Adams (1979) pointed out eight problems with them.

(1) A big difficulty is the underlying assumption that the amount of transfer of training is positively related to the rated similarity between simulator and the real system. Raters have a tendency to report higher transfer effect for simulators with higher fidelity. However, several researchers have shown that high fidelity does not necessarily imply high transfer rate. For example, Johnson (1981) found that training devices do not need to be of high fidelity to be effective in training procedural tasks.

(2) There is evidence that ratings are a function of the amount of experience of the raters. Meshier and Butler (1976) reported an experiment in which experienced and inexperienced pilots were both asked to rate the usefulness of an F4 simulator. Both groups went through the same training procedures before providing the ratings. Twenty-eight per cent of the experienced pilots rated it as "excellent" and sixty per cent of the same group rated it as "good". However, sixty-eight per cent of the inexperienced pilots rated it as "excellent" and only eighteen per cent of that

group rated it as "good".

(3) Experience in the simulator affects the ratings. Gerlach et al. (1975) reported that the pilot's rating of simulator fidelity improves with experience in the simulator.

(4) The dimensions of a simulator interact so that the rating of one dimension is affected by the presence of another.

(5) Raters have difficulty distinguishing human skill deficiencies from the deficiencies of the simulator.

(6) It is not necessarily true that a positive correlation exists between ratings and flying performance in the simulator.

(7) Other factors affecting training effectiveness are not included, e.g., instructors' role and training syllabus.

(8) Experienced users of the real system may not be appropriate raters for the training devices.

## Summary

Rating is an overall judgement of similarity between the responses experienced in the simulator and a memory representation of the responses experienced in the real system. It has been used widely in the evaluation of flight simulators. Several scales were proposed. Two of them were discussed here.

Gerlach et al. adopted a six-point scale, while Cooper and Harper used a ten-point sequential decision scale. Rating is easy to conduct and inexpensive to implement. It can be done before the training program or even before a working simulator is available. Therefore, in considering a predictive index for the effectiveness of the simulator, it is more useful than the transfer of training approach. However, Adams pointed out a few problems with the rating approach. The major drawback is their subjectivity.

## D. SIMULATOR FIDELITY

### DEFINITIONS

"Fidelity" has been used widely and diversely in the simulator training community. Different people use the term with different meanings. Hays (1981) reviewed the literature and noted the diversity of meaning. He further found that most researchers contrasted physical fidelity with non-physical fidelity. It is non-physical fidelity that attracted a variety of names and definitions. Functional fidelity, psychological fidelity, task fidelity and behavioral fidelity (Hays 1980) are among the names used. In general, most researchers agree that physical fidelity is not the only factor, nor the main factor, affecting training effectiveness. There is also general agreement that higher fidelity (assuming it can be measured) is not necessary for every aspect of every kind of training.

There appears to be a lack of research activity on simulator fidelity, and of an appropriate definition of what is meant by fidelity. After reviewing several attempts to define simulator fidelity, Hays (1981) proposed the following definition :

> Training simulator fidelity is the degree of similarity between the training simulator and the equipment which is simulated. It is a two dimensional measurement of

> this similarity in terms of: the physical characteristics of the training simulator, and the functional characteristics of the simulated equipment.

Rouse (1982) defined fidelity:

> "the precision with which the simulator reproduces the appearance and behavior of the real equipment."

These two definitions are very similar. They emphasize that fidelity is a two dimensional concept. They also pointed out the measurement problems. Tasks and the responses of the trainees were not explicitly considered.

According to Kinkade and Wheaton (1972), the fidelity of a simulator consists of three different components: (1) equipment fidelity (2) environment fidelity, and (3) psychological fidelity. Equipment fidelity is defined as the degree to which the simulator duplicates the appearance and "feel" of the real system. Environmental fidelity is concerned with the degree to which the simulator duplicates the sensory stimulation, e.g., dynamic motion cues, visual cues, etc. Psychological fidelity is simply the degree to which the trainee perceives the simulator as a duplicate of the real system. Equipment fidelity is actually what Hays defined as physical fidelity, while the environmental fidelity and the psychological fidelity together approximate his

functional fidelity. However, psychological fidelity explicitly recognizes the role of the trainees' perception of fidelity.

Govindaraj (1983) proposed a three-dimensional approach in which further descriptions and measurements along each dimension are discussed.

(1) Physical fidelity :

Physical fidelity is concerned with the variables presented and the forms they take as well as the environmental factors such as noise, vibration and thermal conditions. Techniques from syntactic pattern recognition are proposed to measure physical fidelity.

(2) Structural fidelity :

Structural fidelity refers to the relationships between subsystems. Level of abstraction, coupling of system states, and aggregation of subsystems are the primary concerns. Graph theoretic methods are proposed for measurement.

(3) Dynamic fidelity :

Dynamic fidelity refers to the evolution of system states over time and their presentation to trainees. Control theoretic methods are proposed for measurement.

This definition appears to be relatively comprehensive and especially useful for describing the fidelity of simulators of large complex systems such as power plant control rooms. Tasks and trainees' feedback are not considered. Non-physical fidelity is decomposed into structural fidelity and dynamic fidelity. This provides a way to analyze and measure the functional aspects of a simulator.

Despite the rigorous attempts to define simulator fidelity, one must keep in mind that training effectiveness is the main concern. If high fidelity does not imply high transfer of training, then fidelity is not a useful concept. As pointed out by Rouse (1982), the key issue in the use of simulators is the level of fidelity necessary to assure transfer of training from simulators to real equipment. The study of simulator fidelity can help clarify the following questions.

1). What are the variables affecting the feeling of realism?

2). What is learned and in what way?

3). Can a criterion for simulator design be found?

4). What is the relationship between each dimension of fidelity and transfer of training ? Or, does any meaningful relationship exist between these two?

An empirically sound definition of fidelity is necessary if

any further study of fidelity is anticipated. It may not be possible to have a general index of fidelity for design purposes. Nevertheless, an explicitly expressed and commonly accepted definition is required for comparison of fidelity between different simulators.

## RELATIONSHIP WITH TRAINING

A hypothetical relationship among fidelity, transfer, and cost was proposed by R. B. Miller (1954) (see Figure 2). Very little empirical data have been collected to explore this relationship. According to Miller, an increase in the degree of simulator fidelity is accompanied by increases in both transfer of training and cost. The objective both for simulator design and the use of a simulator for training, is to find the optimal point of intersection between fidelity, transfer and cost in each case. One problem with Miller's formulation is that the cost of a simulator could go to infinity as its fidelity increases(Orlansky 1984). Another problem is the explicit assumption that the amount of transfer increases with increasing fidelity of the simulator (Micheli 1972). Many researchers have found that comparable training results may be obtained with both low- and high-fidelity simulators of the same equipment (Duncan and Shepherd 1975, Crawford and Crawford 1978, Johnson 1981). In a study by Martin and Waag (1978), it was shown that flight simulators with higher fidelity provided too much information for

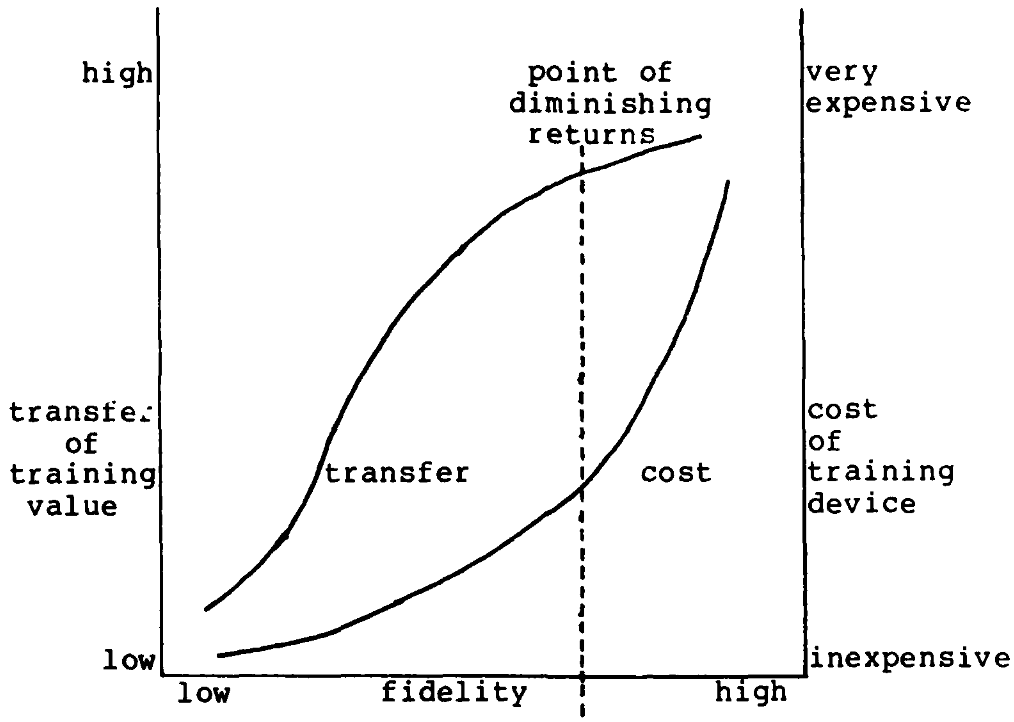


Figure 2 : The hypothetical relationship among fidelity, transfer and cost (modified from Miller 1954)

novice trainees and actually detracted from simulator effectiveness. Prophet (1966) reported a study that compared a low fidelity simulator (inexpensive photographic mock-up of a cockpit) with that of an elaborate trainer. No significant difference between groups was found. Despite these counterexamples, Miller's approach is cited widely (Fink and Shriver 1978, Kinkade and Wheaton 1972, Hays 1981).

A reformulation of Miller's view has been proposed by Orlansky (Orlansky 1984). Even though Orlansky's hypothetical model is not fully supported by empirical data, the known facts about the cost of simulators and about the relationship between transfer of training and fidelity have been accounted for in the model.

Kinkade and Wheaton (1972) have proposed a hypothetical relationship between the degree of simulator fidelity, types of simulator fidelity and the stages of learning (see Figure 3). Early in the training program (procedure training), the trainee cannot benefit from high degrees of either physical or environmental fidelity. However, as skill is acquired (familiarization training), there are requirements for increases in both physical and environmental fidelity, with the requirements for greater environmental fidelity increasing at a faster rate. During later stages of training (skill training), increases in both types of fidelity are desirable, with a

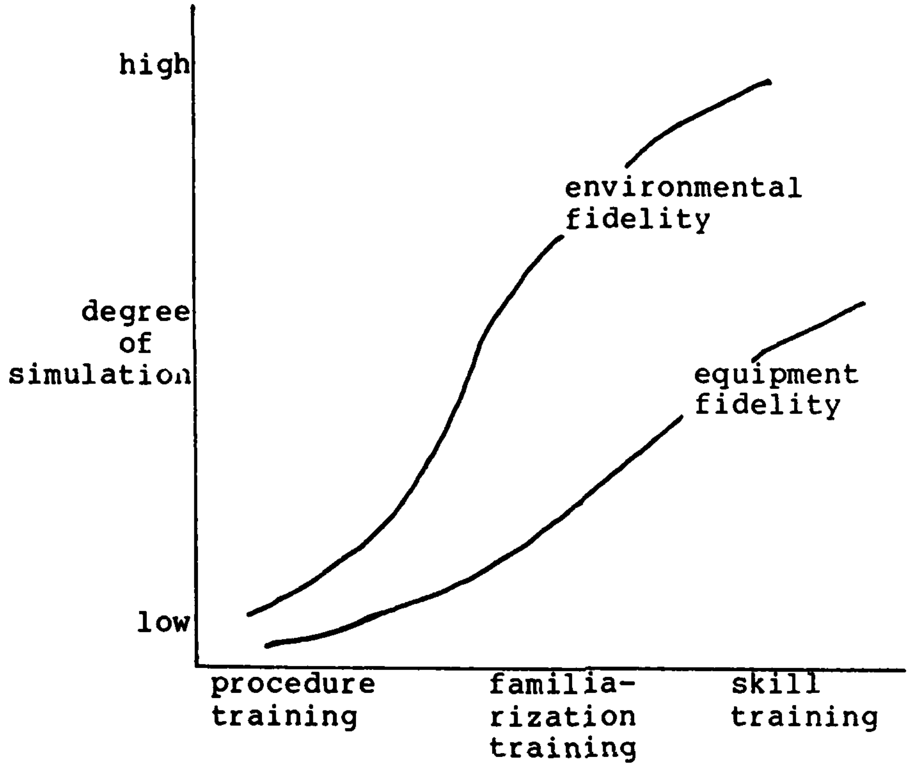


Figure 3 : The hypothetical relationship among degree of simulation (fidelity) and stage of learning (Kinkade and Wheaton, 1972)

requirement for higher levels of functional fidelity.

Johnson (1981) was able to show that high fidelity is not required for training in procedural tasks. Johnson and Rouse (1982) reported similar results for fault diagnosis tasks. Govindaraj (1983) also cast doubt on the necessity of high physical fidelity for problem solving training. Baum (1981) pointed out that empirical data to support Kinkade and Wheaton's conjecture are lacking except those for procedure training. Baum, Riedel and Hays (1982) conducted a study to determine the relationship between training device fidelity and transfer of training for a perceptual-motor maintenance task. The results indicate that physical similarity is a significantly more important determinant of skill acquisition than functional similarity. These experiments provide some support for Kinkade and Wheaton's proposal.

Fink and Shriver (1978) made a point similar to that made by Kinkade and Wheaton. They identified four training stages: (1) acquisition of enabling skills and knowledge (2) acquisition of uncoordinated skills and unapplied knowledge (3) acquisition of coordinated skills and ability to apply knowledge and (4) acquisition of job proficiency. They claimed that different stages require different levels of fidelity with the first stage requiring the lowest level.

G.G. Miller (1974) drew the following conclusions about the relationship between fidelity and training.

(1) High fidelity is never associated with poor training.

(2) Transfer of training is more a function of how the simulator is used rather than the degree of fidelity.

(3) Procedural task training does not require high fidelity.

Conclusions two and three are shared by many other researchers, while conclusion one is doubtful as pointed out before.

No consensus has been reached on the relationships between fidelity and other factors such as cost, training, and stage of learning. The research in this area is not very conclusive. The difficulty of measuring fidelity is part of the reason for the slow progress. The next section discusses the problems and the alternatives for the measurement of fidelity.

## MEASUREMENT OF FIDELITY

The measurement of fidelity is an important step if one wishes to determine empirically the relation between level of fidelity and training effectiveness as well as the necessary fidelity level of a simulator for training for a given task. Specific transfer of training studies are possible only after

both the simulator and the actual equipment have been built. Nevertheless, there is a need to be able to predict the effectiveness of the training device prior to construction. Considering the tremendous cost and man-hours involved in developing simulators of any fidelity level, one cannot be satisfied with a post hoc measure. A measure of fidelity that correlates with the measure of transfer of training is a useful system design guide. Therefore, the purpose of measuring fidelity is the hope that a predictive index can be devised for anticipating the effectiveness of a training simulator. A reliable, predictive index of the effectiveness of a simulator will be very useful both for trainers and design engineers. Other things being equal, such as user acceptance and required levels of funding, they can then choose only those features that possess high transfer value and still meet the training objective. However, in practice this is very hard to achieve due to the difficulty of measuring simulator fidelity. One of the difficulties is the lack of generality of such a measure. Govindaraj (1983) pointed out that the environment and the purpose for which the simulator is to be used have a strong influence on fidelity. Also, fidelity appears to be very context-specific. Therefore, it may be difficult to derive context-free measures of fidelity.

Wheaton et al. (1976) assessed simulator fidelity on two dimensions: physical fidelity and functional fidelity. They

discussed the metrics of fidelity in the context of constructing a model to predict training device effectiveness. In their approach, a thorough task analysis of the target system and the simulator was conducted. Subtasks of the target system and the simulator were then clearly identified. The physical fidelity, for each subtask, between the real system and the simulator was evaluated by rating with a scale that ranged from "no resemblance", "dissimilar", "similar" to "identical". The functional fidelity was evaluated by recording the operator's behavior in terms of the information flow from each display to the operator, and from the operator to each control. For each subtask, the type, amount, and direction of information was assessed using information-theoretic methods. Then a four-point scale was applied by comparing the information metrics between the real system and the simulator on each subtask.

The underlying assumption was that the higher the rating on the assessment factors, the higher the transfer that would take place and the more effective the simulator. However, as pointed out by Adams (1979), rating is very subjective and its reliability is questionable. Further refinement of this assessment process was reported by Narva (1977), in which the physical fidelity and the functional fidelity were measured by rating with emphasis on behavioral categories instead of the original subtasks. Some of the behavioral categories used include rule learning and use, detection, symbol identification,

decision making, etc.

Caro (1970) advocated a procedure called Equipment Device Task Commonality Analysis in which the measurement of fidelity was conducted by assessing the similarity of S-R relationships in the real system and the simulator. Positive transfer was assumed to occur when both stimuli and responses were similar. Negative transfer was predicted when the stimuli were similar but the responses were different. This is similar to what Osgood (1949) proposed. The assessment of the similarity was also accomplished through rating. This procedure applies only to simulators where the stimuli and the responses can be clearly identified. In a complex system, it may be impossible to specify the stimuli clearly.

## COMPONENTS OF FIDELITY

As pointed out in the previous discussion, "fidelity" is a mutli-dimensional concept. An operational, comprehensive definition may be difficult to obtain. However, the building blocks of fidelity have been widely noted and studied for a long time. These are the design features of a simulator. Some of them are discussed below. This list is definitely not exhaustive.

## Stress

There is no doubt that stress is experienced by most operators of any real system. However, as Duncan and Shepherd (1975) pointed out, it is not clear how or if stress can be simulated during training. There are at least three types of stress. First, there is the feeling of danger. Creating this type of stress on a simulator during training is very difficult. Second, there is the threat of hazard or sanction. This form of stress can only be simulated by manipulating reward as a consequence of performance. Third, there is time stress. This can easily be introduced into the training task, but may alter the trainee's perception of the task. Not much is known about how to incorporate stress into simulator training or if its presence contributes to adequate training (apart from user acceptance or irrelevant opinion).

## Environment

Noise is distracting especially in complex tasks that require close attention and concentration (Finkelman 1975). Improper lighting (Tinker 1943), temperature (Pepler 1972), etc. degrade human performance. However, how much these affect the fidelity level or how much they contribute to the training effects is a matter difficult to estimate. While noise, inappropriate lighting, and temperature may degrade general

performance, systematic noise or unusual heat or temperature are repeatedly reported to be of a great help for failure detection and diagnosis. Many trainees, designers and experienced operators admit the possibility of using unusual environmental changes as a clue to detect or diagnose the failure. Vibration has been given the same appraisal (Longman, Phelan and Hansford 1981, McCallum and Rawson, Jaspers and Hanley 1980, Semple et al. 1981, Martin and Wagg 1978).

Layout

Panel layout, display size and even the coloring of instruments are considered to be important factors that affect the feeling of realism. More important is the relative distance and the relative position between gauges, annunciators and status indicators (Fowler et al. 1968). Duncan and Shepherd (1975) argued that the trainees may develop strategies that heavily depend on patterns of the presented stimuli. The size of the display may influence the amount of information the trainee can process at any one time. The relative distance between gauges and the relative position of stimuli may affect the pattern recognition process. However, Duncan and Shepherd pointed out that the influence of such factors is unkown.

<u>Wholeness</u>

A full-scale simulator provides all aspects of system training, while a part-task simulator presents only selected parts of the full system to the trainees. The benefit of a part-task trainer is that some particular important subsystem such as the turbine or the boiler may be represented with greater physical fidelity and provided for training before coping with the entire system. However, the functional fidelity may be affected due to the isolation of a particular subsystem. Curry (1981) observed that detection, diagnosis and remedial action are generally assumed to be three separate tasks. Therefore, training on each one can be accomplished independently without too much trouble. Rouse (1981) found that a particular logical judgement process is especially important for effective fault diagnosis. Abstracting this logical process, he developed a context-free task, TASK, which is in some sense a decomposition of the fault diagnosis behavior. He demonstrated positive transfer of training from TASK to a real system. Rasmussen (1980) proposed a criterion for the decomposition of a complex function. He obsered that:

> "...break-down of complex functions is only acceptable if the performance is paced by the system, i.e., cues from the system serve to initiate elementary, skilled sub-routines individually and to control their sequence. This is the case in many manual tasks, e.g.,

> mechanical assembly, but can probably also be arranged in more complex mental tasks by properly designed interface systems." (p. 92)

The influence of the part-task trainer on complex mental tasks, such as fault diagnosis and problem solving, is not yet clearly understood. However, the unverified conjecture is that wholeness is not a crucial fidelity factor.

## Dynamics

Most real systems are dynamic, as are most simulators. However, static simulators have been used increasingly in the past few years (Duncan and Shepherd 1975, Shepherd et al. 1977, Hunt and Rouse 1981, Johnson and Rouse 1982). Static simulators only allow the operators to check the system status, while dynamic simulators accept control commands and execute them. There is no doubt that dynamic simulators describe the object task better than static simulators do, but how much better is a question unanswered. Forbus and Stevens (1981) indicated that there is a growing amount of evidence that human understanding of physical systems is based on qualitative models of those systems. This evidence comes from psychological studies (Larkin et al. 1980) and is supported by success in artificial intelligence in actually constructing systems that reason about physical situations using qualitative models (deKleer 1979, Forbus 1980). Govindaraj (1983) proposed a qualitative approach to modeling a

complex dynamic system. This approach may provide a way to associate the level of dynamic fidelity with an explicit training effect. However, there is no empirical data to support the transfer effect of the qualitative dynamic simulator.

## Abstraction

A physical system can be represented mentally in different forms (Rasmussen 1979). Simulators may be constructed to represent the physical system at different levels of abstraction. On the bottom of the hierarchy is the realization of the physical components in detail, analogous to a system mock-up. The higher the model stands in the hierarchy by aggregating elements into larger units or by abstracting through functional properties, the less the physical fidelity becomes. A system block diagram is an example of a more abstract simulator. Each level of abstraction possesses its own set of symbols and syntactic rules. Abstract simulators may be more effective in training for fault diagnosis due to the absence of irrelevant cues. Rasmussen argued that shifting between levels of abstraction for suitable strategy may be helpful for problem solving. This implies that training under lower physical fidelity and higher abstraction level may transfer well to higher physical fidelity and lower abstraction situation. The fact that diagnosis can be viewed as a top-down process may explain why lower physical fidelity and higher abstraction level simulators could perform better in this type of training.

Therefore, functionally speaking, it is hard to decide which one has higher fidelity.

The value of simulators of different abstraction levels may be different for different levels of trainees. Kriessman (1981) speculated that simulators of different fidelity level may achieve the training effect differently. A high fidelity simulator is good for more experienced trainees, while a low fidelity simulator is better for less experienced ones. However, it is still an open question as to whether the use of simulators of different abstraction levels may provide the operator with different skills or the same type of skills but in a degraded mode.

## State Variables

Most of the state variables in a real system are presented in a continuous manner via gauges and meters, while for simplification, some simulators may represent the state variables in discrete language such as high/medium/low or on/off. Internally, the human processes information in a discrete manner, especially when logical reasoning is involved. He may classify information into several finite sets. Presenting information in a discrete manner may not result in a loss of information as long as the classifying scheme matches the human's internal model.

The increasing use of CRTs for display in simulators introduces difficulty in presentation of state variables because

of size constraints. The most common strategy is to use serial presentation instead of parallel presentation which is the usual way information is transferred to the operator in a real system. However, considering the human as a limited information processor, this restriction may not be as serious a fidelity problem as it first appears. The attention span for human beings is well known to be narrow and varying in time. The state variables in a real system, though presented simultaneously, are possibly processed in a serial manner----perhaps chunk by chunk. However, how serial presentation of state variables affect fidelity may depend on the type of simulators used.

## SUMMARY

Several attempts have been made to define "fidelity". Hays (1981) proposed a functional fidelity vs. physical fidelity approach. Rouse (1982) suggested a similar idea. Govindaraj (1983), oriented toward an operational definition, decomposed functional fidelity into structural fidelity and dynamic fidelity. Lack of empirical studies of fidelity issues makes it difficult to develop a useful definition of fidelity. A generally accepted assertion is that higher fidelity does not guarantee better transfer. Kinkade and Wheaton (1971) conjectured that the fidelity requirement varies with the stages of learning. Generally, it is proposed that procedural tasks do not require as high a fidelity as visual-motor skills do.

Wheaton (1976) and Narva (1977) developed a predictive index for transfer effect based on the measurement of fidelity. Task analysis of both the real system and the simulator is the foundation for measurement. Rating, so far, is employed in almost every fidelity metric. A more objective metric based on system characteristics, and perhaps learner state only, is an important future research topic.

Several factors that affect fidelity were also discussed. A brief summary is reproduced below.

(1) It is very difficult to include stress in the simulator.

(2) Environmental factors such as noise, lighting, temperature, motion and vibration are annoying but may be treated as diagnostic aids. Inclusion of these variables does increase fidelity, but the cost-effectiveness of including them in a simulator has long been challenged.

(3) Layout may affect the strategy used by trainees.

(4) The important issue in the use of part task simulators is the decomposibility of the tasks.

(5) Dynamic features may not be crucial in training for fault diagnosis. Several studies indicated that the human reasons in a qualitative rather than quantitative way. This suggests an important research topic.

(6) It may be beneficial to vary the level of abstraction of the simulator depending upon the level of skill of the trainee.

(7) in a real system, the state variables are presented simultaneously, although humans may not be able to process all of this information at once. As a limited information processor, human operators may do well with serial presentation of the state variables.

Research on simulator fidelity is geared toward better understanding of the learning process and the construction of a predictive index of transfer effect. These as well as other promising research topics are discussed in the following section.

## E. FUTURE RESEARCH

A majority of the research on simulator training has concentrated on normal operation. However, the increasing use of automation in large complex systems has made the human operator more of a monitor or a supervisor who only interacts with the system when failures occur. This tendency results in the increasing emphasis on fault diagnosis training. Future research on simulator training is largely influenced by this trend. Another area worth noting is that new technologies like videodiscs and computer graphics are gradually changing the characteristics of simulator training. Klein et al. (1978), Swezey (1981), and Levin and Fletcher (1981) were concerned with these. An extension of what they presented is discussed below. Studies related to each topic are supplied when available. This is not intended to be exhaustive because the research on simulator training is multi-directional.

### NEW TECHNOLOGY

Advances in microprocessors, videodiscs and computer graphics have led to drastic changes in the design of real systems and simulators. Berman (1981) reported that General Electric's Nuclenet 1000 control system uses 10 CRT's to replace as many as 75 percent of the components previously used on vertical control boards. Kaplan (1983) depicted a venture in which a nuclear-power-plant malfunction analyzer was built by

using advanced graphics technology. Levin and Fletcher (1981) advocated the use of videodiscs for training. The benefits of using videodiscs in training equipments, they claimed, were low cost and flexibility. Videodiscs actually combine the advantages of text, slide, movie, audio and computer. Bunderson and Campbell (1980) discussed some of the problems in adopting videodiscs as training equipment. They claimed that videodiscs are not well suited as training devices at the current stage of development, but promise to be useful in five years.

## VALIDATION OF MODELS

Most of the models and guidelines used in the evaluation of transfer effects are theoretical constructs. Validation and experimentation are required. For example, Wheaton et al. (1976) proposed a predictive index of transfer effects based on the training program and simulator fidelity. Though modified later by Narva (1977), they report no empirical data since then.

## ACQUISITION AND DECAY OF TRAINING

There is very little applicable, quantitative information available on learning curves and learning decay (retention of training) for different types of task and training method. The impact of time and intensity of training on the acquisition of learning is a critical question with implications for cost and cost-effectiveness. Using a Thomas table-top collator, model T-8, Weitz and Adler (1973) showed that male trainees should not

be trained beyond the point at which they have reached some minimal criterion of performance. Overtrained male trainees tended to develop simulator-specific habits which interfered or became dominant factors in real world performance. Aspects of the basic learning process like these may be incorporated into training device design in the hope that the transfer effect can be increased as much as possible. However, very little is known about these issues.

## INDIVIDUAL DIFFERENCES

There is an increasing awareness that training devices are most successful when tailored to the particular "cognitive style" and "capabilities" of the trainee. The ACTS (Adaptive Computer Training Systems) reported by Freedy and Lucaccini (1981) is an attempt in this direction. A utility decision model is employed to estimate the "capabilities" of the trainee. Individualized instruction is then given to the trainee based on the result of the estimation.

"Cognitive style" --- that of impulsivity-reflectivity ---was reported to be a reasonable predictor of errors on fault diagnosis tasks (Henneman and Rouse 1984). It is therefore reasonable to speculate that training for fault diagnosis tasks should fit one's cognitive style. However, very little research has been conducted in this direction.

## SKILL LEVEL VARIANCES

As skill levels vary across trainees, so perhaps should the type of device used. Kriessman (1981) speculated that a high fidelity simulator is good for more experienced trainees, while a low fidelity simulator is good for less experienced trainees. This is the assumption that underlies the proposal of a mixed-fidelity approach to simulator training by Rouse (1982) and Johnson and Rath (1983). The effectiveness of training of this kind remains to be fully verified.

## PERFORMANCE MEASUREMENT

Adequate measures for human problem solving performance are the basis for transfer effect experiments, especially those on fault diagnosis training. Henneman and Rouse (1984) have conducted extensive research on this topic. They indicated that there are only three unique dimensions of performance: errors, inefficiency and time. In addition, cognitive style appears to be a reasonable predictor of performance. How well these metrics can be applied to types of training other than fault diagnosis is not yet determined. Also, whether these variables affect the design of a simulator is not clear.

## DECISION AIDS

Decision aids in a training simulator help trainees learn efficiently. However they may not reside in the real system. The decision aids may help the trainees substantially but leave

them hopelessly desperate when transferred to the real system because of the unavailability of these aids. This sort of aids should "fade out" (Goodstein 1981) before transferred to the real system. How and when to fade out aids is an idea worth pursuing.

## MENTAL MODELS

Mental models are internal representations of the external environment. They can assist human reasoning by producing explanation or justification of complex system behavior. They are powerful analogical devices humans use in learning (Montague 1981). Landeweerd (1979) indicated that mental models probably played an important role in fault correction and in the verification process in diagnosing faults. Prather (1973) showed that mental practice of landing the T-37 aircraft could improve the actual performance. However, it is not known how mental models might be used in designing training equipment, or how a mental model might affect the learning of a skill.

## F. CONCLUSION

Simulators have long been used as training devices due to belief in their cost effectiveness and flexibility. New technology may have changed the characteristics of the physical configurations of the simulators. However, the basic problems of using simulators for training still remain. Transfer effect, fidelity level and their relation to cost are three of them.

The main techniques used to measure the transfer effect are transfer of training and ratings. Transfer of training research uses a fixed paradigm in which the experimental group goes through both simulator training and real system training while the control group experiences only the real system training. Several performance measures have been devised to assess the effect of simulator training on performance on the real system. They can be classified into either time savings measures or first-shot performance measures. Savings measures determine the savings of training efforts on real systems. The first-shot measure evaluates the performance of the trainees on the first trial after transferring to a real system.

The main difficulty in using transfer of training is that it becomes useless if no control group can be formed. This situation occurs frequently in training for normal operation. Alternatives such as in-simulator transfer of training have been

proposed and used, but not widely. Another problem with transfer of training research is the unavailability of the target task in the real system. In fault diagnosis tasks, a formal transfer of training study cannot be conducted simply because of the infeasibility of producing the fault situations in the real system. A modification of this is to treat fault diagnostic behavior itself as the target task instead of specific failures.

Ratings are inexpensive and convenient to perform. However, they are subjective and have limited reliability and validity. Nevertheless, ratings when used with task analysis, are the basis of a predictive model for simulator training effects. Despite severe theoretical drawbacks, ratings are still adopted widely in practice.

"Simulator fidelity" has been used to describe how the simulator resembles the real system. It is generally accepted that both physical fidelity and non-physical fidelity are factors which influence the transfer effect. However, there is no consensus on what non-physical fidelity is. To reach a possible consensus on the definition of simulator fidelity, a thorough investigation of its relationship with training and its components is required. Most of the frequently described relationships among fidelity, transfer, and cost are hypothetical. Very little empirical data have been collected to support these supposed relationships. However, there are two

assertions about the relationship between fidelity and types of task that are supported by empirical research. They are: (1) perceptual-motor coordination tasks require higher fidelity, and (2) procedural task training does not require high physical fidelity.

To study systematically the relationships between fidelity and other factors, a reliable measure of fidelity is necessary. Most of the measures of fidelity are based on task analysis and ratings. These measures emphasize the human's reaction to the system instead of the system characteristics. A fidelity measure based on the system characteristics such as the structure, the dynamics, etc., will be more fruitful.

The components of fidelity presented are those that affect training. Human factors and cognitive psychology points of view have been used to study stress, environment, layout and wholeness. Their influences on fidelity are relatively obvious. How level of abstraction, dynamics and state variables affect simulator fidelity is still under investigation. In the context of simulator training for fault diagnosis tasks, the latter three factors are receiving more attention.

The distinction between training for normal operation and training for fault diagnosis is very important. Training for normal operation emphasizes visual-motor coordination tasks while

training for fault diagnosis is cognitive-task oriented. Increasing use of automation in complex systems has made the latter more important. This trend coupled with the impact of new technologies has attracted considerable research. Several future research topics were outlined, including validation of models, acquisition and decay of training, individual differences, skill level variance, performance measures, decision aids, mental models and fidelity effect.

Simulator training is becoming more and more important, due to the increasing trend toward large complex systems. However, very little has been done to enhance our understanding of the factors affecting its effectiveness. This report has tried to piece together the research that has been accomplished so far into a systematic framework. It is only the beginning of further research.

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Navy

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|---|---|---|
| 1 | Ahlers, Robert | 0 345 |
| 1 | Aiken, Ed | |
| 1 | Baker, Meryl S. | 3 5 |
| 1 | Blaiwes, Arthur S. | 3 |
| 1 | Bond, Nick | 1234 |
| 1 | Breaux, Robert | 0 |
| 1 | CNET Liason, AFHRL | 0 345 |
| 1 | Collyer, Stan | 12345 |
| 1 | CURRAN MIKE | 12345 |
| 1 | EDDOWES, EDWARD E. | |
| 1 | HOLLAN JIM | 2345 |
| 1 | Hutchins, Ed | 345 |
| 1 | KERR NORMAN J | 12345 |
| 1 | MALOY WILLIAM L | 12345 |
| 1 | McLachlan, Joe | 3 |
| 1 | McMichael, Jim | 3 |
| 1 | Montague, William | 0 2345 |
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| 1 | Smillie, Robert | 4 |
| 1 | Smith, Robert G. | 012345 |
| 1 | SMODE ALFRED F | 2345 |
| 1 | Snow, Richard | 12345 |
| 1 | SORENSEN RICHARD | 12345 |
| 1 | Steinheiser, Frederick | 0 345 |
| 1 | WEISSINGER-BAYLON ROGER | 2345 |
| 1 | Wetzel, Douglas (NPRDC) | 012 45 |
| 1 | Wulfeck, Wally | 3 |

Marine Corps

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| 1 | GREENUP H WILLIAM (MCDEC) | 12345 |
| 1 | ONR 100M | 12345 |
| 1 | SLAFKOSKY AL | 12345 |

Army

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| 1 | FARR BEATRICE | 2345 |
| 1 | O'Neil, Harry | 345 |
| 1 | Orasanu, Judith | 345 |
| 1 | SASMOR ROBERT | 12345 |

Air Force

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|---|---|---|
| 1 | AFOSR Life Sciences | 12345 |
| 1 | DALLMAN, BRYAN | 3 5 |
| 1 | HADDAD GENEVIEVE | 2345 |
| 1 | Longridge, Tom | 0 2345 |
| 1 | Tangney, John | 1234 |
| 1 | Yasatuke, Joe | 2345 |

| Department of Defense | | Civilian Agencies | |
|---|---|---|---|
| 12 DTIC | 12345 | 1 Molnar, Andrew R. | 0 2345 |
| 1 OUSDRE | 12345 | 1 WITHROW FRANK | 2345 |
| 1 Thorpe, Jack A. | 345 | 1 Young, Joseph L. | 012345 |
| 1 WISHER ROBERT | 12345 | | |

| Private Sector | |
|---|---|
| 1 Anderson, John R. | 2345 |
| 1 Anderson, Nancy S. | 0 |
| 1 BAGGETT, PATRICIA | |
| 1 Brown, John Seeley | 345 |
| 1 Bryan, Glenn | 1234 |
| 1 Buchanan, Bruce | 345 |
| 1 CARBONELL, JAIME | 345 |
| 1 Charney, Davida (CMU) | 0 34 |
| 1 CHI MICHELINE | 45 |
| 1 Clancey, William | 0 345 |
| 1 COLE, MICHAEL | |
| 1 COLLINS ALLAN M | 345 |
| 1 DONCHIN EMMANUEL | 12345 |
| 1 ERIC | 12345 |
| 1 Ericsson, Anders | 2345 |
| 1 Feurzeig, Wallace | 0 345 |
| 1 FITZGERALD DONALD | 12345 |
| 1 Fletcher, Dexter | 12345 |
| 1 FREDERIKSEN JOHN R | 12345 |
| 1 Gentner, Don | 2 4 |
| 1 Gentner, Dedre | 34 |
| 1 Glaser, Robert | 012345 |
| 1 GOGUEN, JOSEPH | 2 45 |
| 1 Gopher, Daniel | 2 45 |
| 1 GREENO JAMES G | 12345 |
| 1 Hayes-Roth, Barbara | 2345 |
| 1 Heller, Joan | 34 |
| 1 HOFFMAN JAMES | 2 45 |
| 1 Holland, Melissa | 34 |
| 1 Human Intelligence Newslett | 0 2345 |
| 1 Hunt, Earl | 0 2 45 |
| 1 KIERAS DAVID | 2345 |
| 1 Kosslyn, Stephen | 012 45 |
| 1 Langley, Patrick | 345 |
| 1 LARKIN JILL | 2345 |
| 1 Lesgold, Alan | 012345 |
| 1 LEVIN, JIM | 345 |
| 1 Lyon, Don | 1234 |
| 1 McClelland, Jay | 2 45 |
| 1 Miller, James R. | 345 |
| 1 MILLER MARK | 12345 |
| 1 Moran, Tom | 45 |
| 1 MUNRO ALLEN | 2345 |
| 1 Norman, Donald A. | 0 2345 |
| 1 Orlansky, Jesse | 012345 |
| 1 PENNINGTON, NANCY | 345 |
| 1 POLSON PETER | 2345 |
| 1 POSNER MIKE | 2 45 |
| 1 Reder, Lynn | 34 |
| 1 Reif, Fred | 0 2345 |
| 1 RESNICK LAUREN | 2345 |
| 1 RICHARDSON, JEFF | 5 |
| 1 Riley, Mary | 0 45 |
| 1 ROSE ANDREW M | 12345 |
| 1 Rothkopf, Ernst | 012345 |

| Private Sector | |
|---|---|
| 1 RUMELHART DAVID | 5 |
| 1 DONCHIN EMMANUEL | 12345 |
| 1 Sinaiko, H. Wallace | 0 345 |
| 1 SMITH EDWARD | 2 45 |
| 1 SOLOWAY, ELIOTT | 345 |
| 1 Spoehr, Kathryn T. | 2345 |
| 1 Sternberg, Robert | 0 2345 |
| 1 Stevens, Albert | 0 2345 |
| 1 Tatsuoka, Kikumi | 012345 |
| 1 Tatsuoka, Maurice | 1 34 |
| 1 Thorndyke, Perry | 0 345 |
| 1 Towne, Doug | 0 345 |
| 1 Van Lehn, Kurt | 345 |
| 1 Wescourt, Keith T. | 0 345 |
| 1 Whitten, William B. | 0 2345 |
| 1 Wickens, Christopher | 0 2 45 |
| 1 Wickens, Tom | 4 |
| 1 WILLIAMS, MIKE | 345 |
| 1 Wohl, Joseph G. | 34 |

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8